RESEARCH HIGHLIGHT

June 2007 Technical Series 07-108

Boiler Piping Study

INTRODUCTION

This study examined the factors to consider when replacing boilers with a compact, gas-fired boiler. As there is no generic name for this type of boiler, the term "FARC" boiler, an acronym for "fan-assisted radial copper-tube," was coined. FARC boilers have become very popular for retrofit work. First introduced in the mid-1980s, FARC boilers are characterized by a barrel-shaped heat exchanger made up of copper fin-tubes, with a fan-assisted burner firing down into the center of the "barrel." These boilers are typically available with inputs of 1,055 megajoule to 3,165 megajoule (1 to 3 million Btuh) Larger capacities are available from some manufacturers. Examples of this type of boiler include: A.O. Smith Legend, Camus Dynaflame, Lochinvar Power Fin, Patterson-Kelly Mod-U-Fire and RBI Futura. Most of these boiler models are now into their second or third generation of development.

FARC boilers are well-suited to replace existing boilers. They are more efficient than atmospheric boilers and are smaller and lighter than other boilers of similar capacity and efficiency. This makes them ideal where access or weight is an issue. As they can withstand higher pressures than cast-iron boilers, they may be suitable for installation in the basement boiler rooms of very tall buildings. The low mass nature of these boilers, however, has an impact on their application.

METHODOLOGY

This study examined four boiler plants, each with different piping configurations, to determine what changes the heating system piping and pumping would require to accommodate installation of FARC boilers.

Briefly, the boiler plants studied were:

- **Case study 1:** a penthouse boiler plant with two, bent water-tube boilers using a motorized, three-way mixing valve with an outdoor reset controller to moderate supply temperature, and a single distribution pump. The distribution system consisted of baseboard convectors with electric shut-off valves activated by wall-mounted thermostats.

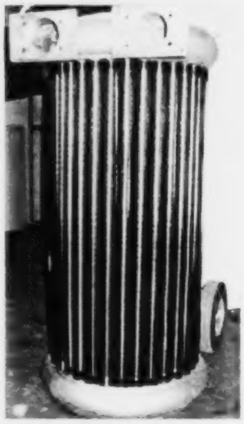

Figure 1 FARC boiler Heat Exchanger

- **Case study 2:** a penthouse boiler plant with two, fire-tube boilers. This plant had four heating zones, each with its own pump. The two zones heating the suites had three-way mixing valves. These zones had a bypass circuit to prevent the pumps from deadheading when the radiator valves closed. In addition, there were circuits that had no mixing valve and ran at constant flow serving the parking garage and common areas. The main heating plant also heated domestic hot water from two tanks equipped with heat exchanger bundles.
- **Case study 3:** a basement boiler plant with two atmospheric boilers with primary-secondary pumping. The boiler had a single, motorized three-way mixing valve with an outdoor reset controller to control the temperature to the distribution system. The domestic hot water was heated, through a heat exchanger, by the return circuit to the boilers.
- **Case study 4:** a penthouse boiler plant. The heating system had two zones, each its own circulation pump, and two boilers piped in reverse-return configuration. Recorders logged the supply and return water temperatures of the boilers in each plant.

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In case studies three and four, this data was used to calculate the flows through the boilers. Case studies one and two had modulating burners. The flows through these boilers could not be calculated in the same way, so a logging, ultrasonic, flow meter recorded the flows. This information was used to determine if the flows and temperatures in each system would be appropriate for the use of FARC boilers, and, if not, what changes in the pumping and piping would be required to accommodate FARC boilers.

OBSERVATIONS

Case study 1

The researchers found the flows through the existing boilers to be variable. This was due to the action of the electric valves. As the call for heat in each apartment is satisfied, the valves on the convectors shut off the flow, a condition most pronounced in the shoulder seasons. In addition to this, the flow varied continually by about 20 per cent. This was due to the action of the motorized, three-way mixing valve. The unequal pressure on the two "'in" legs of the line-sized valve combined with the variable temperature return water resulted in the valve "hunting" to try and meet the send-out temperature set point. This is shown in Figure 2.

Case study 2

The flows through the boilers were more constant in this boiler plant. Although the motorized radiator valves restricted flow in some circumstances, as in Case study 1, the two constant-flow zones and the domestic hot water circuits ameliorated the variable flow in the two zones serving the suites.

Case study 3

This boiler plant had a bypass circuit, which prevented the operation of the three-way mixing valve from varying the flow through the boilers. However, the domestic hot water was heated through a heat exchanger pumped from the return piping. This caused the return-water temperature to the boilers to be, at times, as low as 110°F (43°C).

Case study 4

This boiler plant was about as simple one can be. At times the return-water temperature was very low. The flow was not variable. The pump head of the existing distribution pump would be insufficient, however, to accommodate the extra pressure drop through FARC boilers.

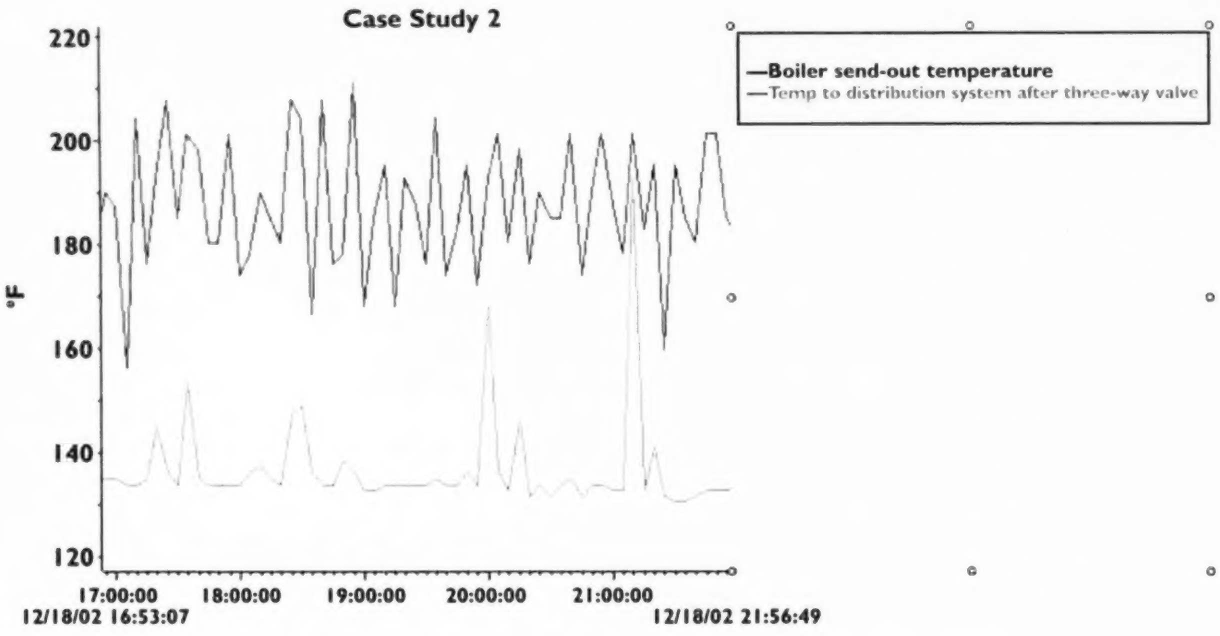

Figure 2 Fluctuation in temperature from three-way valve

KEY FINDINGS

Not all piping circuits ensure proper flow through the boilers

Proper flow, and consequently the temperature rise (ΔT), through FARC boilers is critical. Too little flow can overheat the heat exchanger, shortening its life. Too high a flow can scrub the heat exchanger tubes, causing pitting and early failure. Three of the four boiler plants studied used the main circulating pumps to provide flow through the boilers. Because of the higher pressure drop through FARC boilers, these pumps would not provide sufficient flow with these boilers installed. In all case studies, replacement FARC boilers would require their own circulation pumps. At the most basic, this will result in a primary-secondary pumping arrangement, in which the distribution system is the primary loop and the boiler piping and pumps form the secondary loop.

Variable flow through the boilers can cause rapid cycling

Rapid cycling, firing and then shutting off every few minutes increases wear and tear on the boiler and can increase fuel consumption. Low flow, or variable flow, through the boilers is a primary cause of this. Despite the common assumption that installing FARC boilers into an existing system can be done with little modification as long as they have their own pumps, it was found that this is not always the case.

Under some conditions, when the flow through the boiler header is reduced, flow can reverse between the supply and return legs of the boilers (see Figure 3). This will result in the boiler short-cycling. Flow through the boiler header can be reduced through the action of electric or thermostatic shut-off valves in the distribution system. In some cases, motorized three-way valves can also reduce the flow through the boiler header, because they work by mixing return water with supply water, bypassing the boiler circuit.

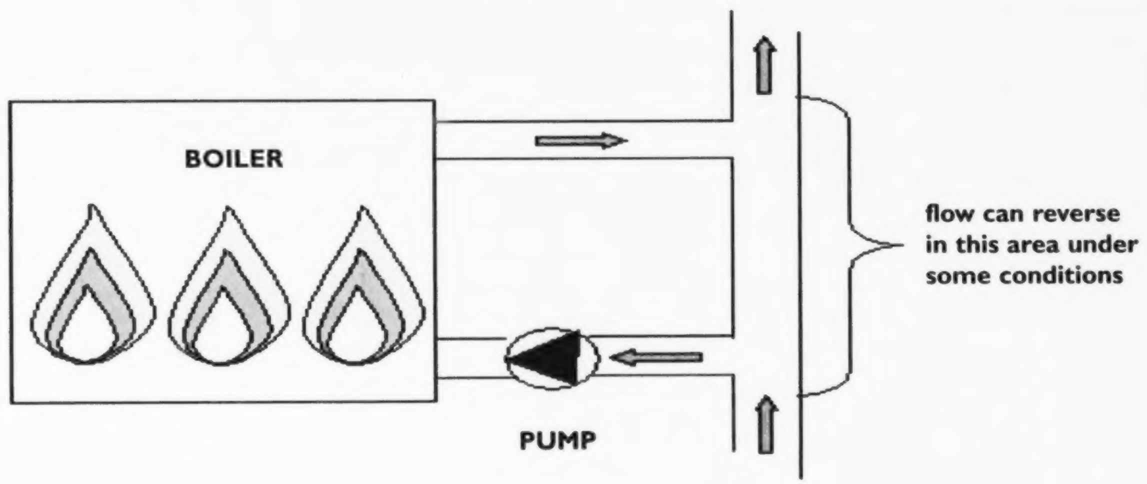

Figure 3 Variable flow in the boiler header can cause rapid cycling of the boiler

FARC boilers must be protected against low return-water temperatures

Several of the boiler plants studied had return-water temperatures low enough to cause the products of combustion to condense. This can damage boiler components and shorten boiler life. If the supply temperatures must be kept low to prevent overheating, measures must be incorporated to protect the boilers from low return-water temperatures. Using a "shunt" across the supply and return legs of the boiler is one way to do this, as Figure 4 shows.

FARC boilers must be kept under pressure

If the water pressure is not maintained within the FARC boiler heat exchanger, steam bubbles can form which can impede the flow of water through the heat exchanger. FARC boilers are more vulnerable to this than boilers with larger heat exchangers. Conditions that could lead to low water pressure include pumping away from the boiler instead of pumping the return water and improper placement or sizing of the expansion tank.

Extra measures are required in dirty environments

The small heat exchangers and small diameter passages of FARC boilers makes them susceptible to fouling from dirty boiler water. None of the boiler plants, including the boiler plant located in a basement, had any equipment installed for removing particulate contaminants from the system water. It was noted that it would be prudent to install strainers on all FARC installations.Typical of the majority of boilers, none of the existing boilers studied had air filters. While many of the newer FARC boilers do have air filters, service personnel may not be used to changing air filters on boilers. Changing the filters has to be added to their maintenance duties.

Adequate instrumentation is needed

The flow and temperature through FARC boilers are important to achieving the maximum service life. The flow is simple to calculate if there is a thermometer on the supply and one on the return of each boiler. The flow through the boiler is inversely proportional to the temperature rise through the boiler. The higher the temperature rise, the lower the flow. If the temperature difference between the return water in and the supply water out (the ΔT) at high fire is known, then it can be compared with the manufacturer's data to ensure it is within the design limits. The flow in U.S. gallons can be calculated using the formula:

G (flow) = Boiler output in btuh / ((Temperature Out - Temperature In) x 500)

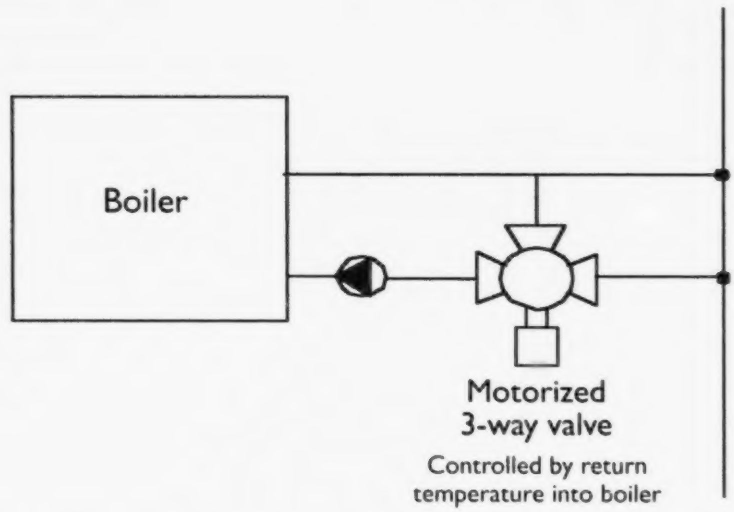

Figure 4 Using three-way valve to protect boiler from low return-water temperature

Designing for maximum energy efficiency

Many buildings are overheated in the shoulder seasons, particularly those using radiators, convectors or radiant panels. This is unavoidable unless the supply temperature to them can be lower than the allowable return-water temperature to the boilers. In mild weather, baseboard convectors, for example, might ideally have a supply temperature of 48.8°C (120°F), but this is too low a temperature to return to the boiler.

A PST (primary-secondary-tertiary) system (Figure 5) utilizing a four-way mixing valve or variable speed injection pumps allows the send-out temperature to the distribution system to be lower than the return water to the boilers. The PST system can be used for multiple zones that require different temperatures (Figure 6). It can be used to heat domestic hot water through a heat exchanger, thus saving capital and maintenance costs by eliminating a separate boiler system.

CONCLUSION

Fan-assisted radial copper tube boilers have many advantages for retrofit work, in large part because they are more compact than other boilers of similar efficiencies. In some applications they are the only economic choice. However, they require a careful analysis of the entire heating system and diligent engineering to ensure maximum efficiency and long service life.

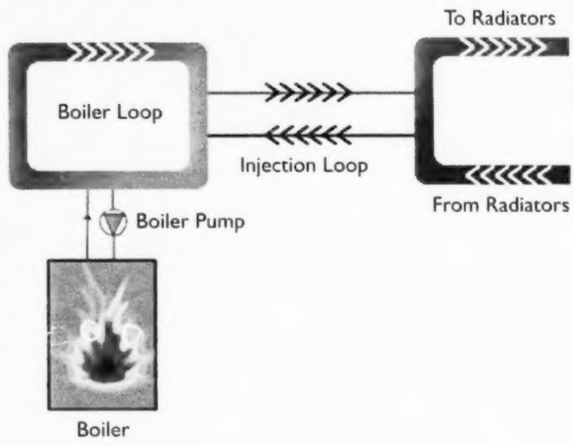

Figure 5 The PST concept

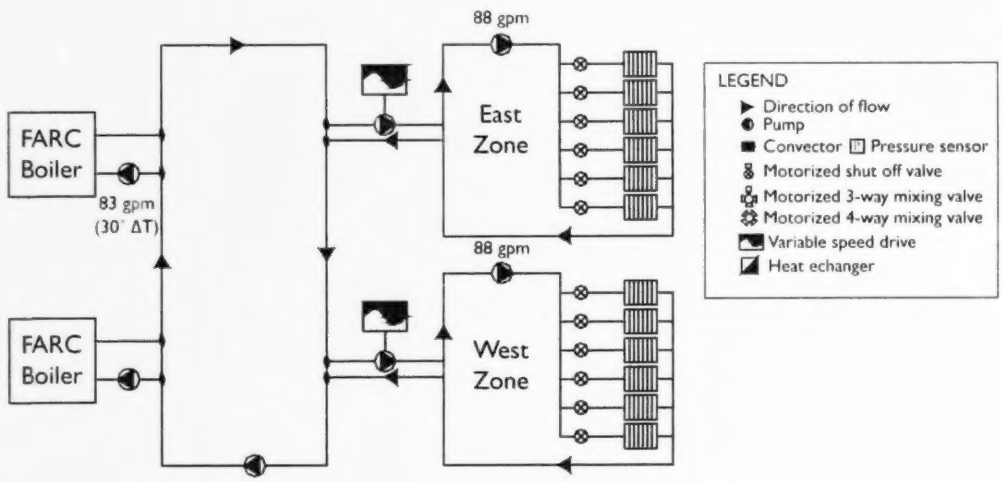

Figure 6 Simplified diagram illustrating the PST system

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